

The effects of ELDRS at ultra-low dose rates

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35-word Abstract: We present results of ultra-low dose-rate irradiations on a variety of commercial and radiation hardened bipolar circuits. We observed enhanced degradations at dose rates lower than 10 mrad(Si)/s in some devices.

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Session Preference: Data workshop

To be presented by Dakai Chen at the Institute of Electrical and Electronics Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) Data Workshop, Denver, CO, July 19-23, 2010 and published in the IEEE NSREC Data Workshop proceedings, July 2010 and on <http://radhome.gsfc.nasa.gov> and <http://nepp.nasa.gov/>.

Introduction

Linear bipolar circuits are known to exhibit enhanced-low-dose-rate-sensitivity (ELDRS) in an ionizing radiation environment. The physical mechanisms for ELDRS have been discussed in numerous past publications, and will not be repeated here [1]. ELDRS has introduced new challenges for radiation hardness assurance. The primary difficulty is the significant irradiation time required to examine a part for ELDRS, which is a burden to a project's schedule and budget. There are several proposed accelerated tests, such as the switch-dose and the elevated temperature irradiation [1], [2]. The elevated temperature method is inconsistent across a variety of devices, for example the LM2941 [3]. The switch-dose method has shown to accurately reproduce low dose rate results [2]. Some issues include the large number of samples required, and the difficulty in finding the transition dose from the threshold to power-law region [2]. The current accepted lot acceptance test, MIL-STD-883G, TEST METHOD 1019.7, requires irradiating bipolar circuits at a minimum dose rate of 10 mrad(Si)/s.

However the saturation point for parametric degradation varies for different parts. In fact, many linear devices exhibit further degradation beyond 10 mrad(Si)/s [1], [4]. Previous studies have shown that parts containing npn input transistors have a damage saturation point at ~ 1 rad(Si)/s, whereas parts with pnp input transistors continue to degrade down to ~ 5 mrad(Si)/s [4]. Nevertheless devices of different processes and/or circuit designs have displayed different levels of dose rate dependence. Manufacturers have since produced parts that are tolerant at low dose rate environments. The ELDRS-free parts, such as the LM136 voltage reference, have exhibited worse degradations at high dose rate relative to low dose rate irradiation [5]. The perpetual introduction of new devices, with various innovative processes and circuit designs, necessitates the understanding of the different degradation behaviors at ultra-low dose rates. Here we examine the effects of ELDRS in a large sample of commercial and radiation hardened devices from different manufacturers, at dose rates of 10, 5, 1, and 0.5 mrad(Si).

Experimental

More than twenty different parts from Linear Technology, Texas Instruments, and National Semiconductor are used in this study. The parts include radiation hardened (lot tested at high dose rate), ELDRS-free (lot tested at 10 mrad(Si)/s), and commercial-off-the-shelf devices. The parts are available in a variety of package types: ceramic, flatpacks, metal cans, etc. In some cases the same part is available in both flatpack and can packages. Previous work has shown that hydrogen contamination from flatpack packages can enhance ELDRS [6]. So we also examine the varying degradation rates that may occur from different packages.

The irradiations are performed with a ^{60}Co gamma ray source at room temperature. The dose rates are 10, 5, 1, and 0.5 mrad(Si)/s. Four to five samples of each part are irradiated at each dose rate. And at least two samples of each part are used as controls. Most of the parts, including voltage regulators and references, are irradiated with all pins grounded. The operational amplifiers and voltage comparators are irradiated with both biased and unbiased (all pins grounded) conditions.

Device Information

Table I shows the parts information for selected parts in this study. Not all parts are included in this summary due to space limitations. The table shows the device functionality, package type, lot date code, and irradiation bias.

Table I. Part information.

Part (package type)/Manufacturer	Function	Lot Date Code	Irradiation Bias
LM158AJRLQMLV (8-lead Cerdip) National Semiconductor	Operational amplifier	7W4453G019	All pins grounded
RH1021CMH (TO5 metal can) RH1021CMW (Flatpack) Linear Technology	5V Reference	RH1021CMH: 9783 RH1021CMW: 0123	All pins grounded
RH1009MW (Flatpacks) RH1009MH (TO46 metal cans) Linear Technology	2.5V Reference	RH1009MW: 0649 RH1009MH: 0829	All pins grounded
TL750L05CDR (8-pin plastic SOIC) Texas Instruments	Low-drop-out regulator ($V_{DO} = 0.6$ V at 150 mA)	June, 2005	All pins grounded

Results

Here we highlight results for select parts, while the irradiation is still ongoing. Figure 1 shows the number of part failures vs. total dose for the TL750L low-dropout voltage regulator manufactured by Texas Instruments. The part failures are characterized by the functional failure of the output voltage (V_{out}). In all instances, the part failed to regulate the proper output of 5 V at 100 mA output load. The initial part failures occur after 40, 20, and 10 krad(Si) for the 5, 1, and 0.5 mrad(Si)/s parts, respectively. In all cases the parts failed abruptly, with no signs of gradual degradations to any parameter prior to functional failure. It is also noteworthy that the TL750M low-dropout-regulator, while similar in function and design, does not show similar functional failure trends up to similar total dose levels as the TL750L.

Figure 2 shows the average input bias current (I_B) vs. total dose for the LM158 operational amplifier manufactured by National Semiconductor. The LM158 is an ELDRS-free version, qualified up to 100 krad(Si) at 10 mrad(Si)/s. The input bias current is taken as the average of the positive and negative inputs on one device for all parts. The error bars indicate part-to-part variation. There is minimal device-to-device variation. The average I_B shows increasing degradation with decreasing dose rate. However part-to-part variation skewed the trend considerably, especially in the 5 mrad(Si)/s data. The enhanced degradations at 5 mrad(Si)/s is mostly the result of 1 part having significantly higher degradations relative to the other parts. Therefore there is not enough conclusive evidence at this stage that indicates dose rate effects. Interestingly, the high dose rate data showed greater degradation than the low dose rates.

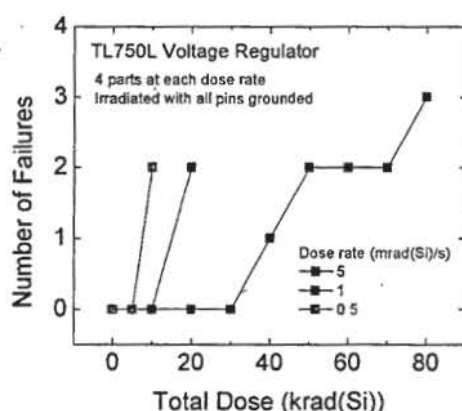


Figure 1. Number of part failures vs. TID for different dose rates for the TL750L voltage regulator from Texas Instruments, irradiated with all pins grounded.

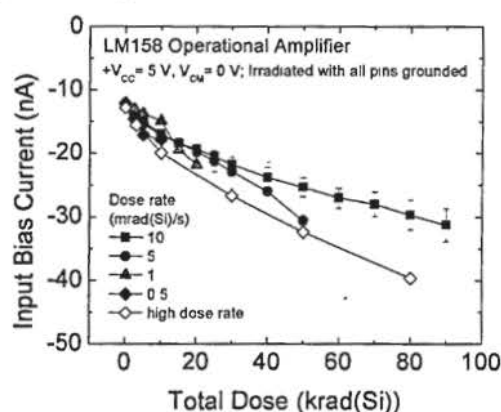


Figure 2. Average input bias current (3 parts with 2 devices each) vs. TID for the LM158 operational amplifier from National Semiconductor, irradiated with all pins grounded.

Figure 3 shows the output voltage vs. total dose for the RH1021 voltage reference manufactured by Linear Technology. The RH1021 is a radiation hardened part that was previously lot tested at high dose rate. The degradations remain within the tested specification limits, which are derived from previous high dose rate testing. The parts at 5 mrad(Si)/s show slightly reduced degradations compared to the high dose rate data at this stage of the irradiation. Also notably, the flatpack packaged parts did not exhibit enhanced degradations relative to the can packaged parts. Therefore there is no evidence of enhanced damage due to hydrogen contamination from the packaging. The degradation levels for all dose rates are similar at this stage of irradiation.

Figure 4 shows the output voltage vs. total dose for the RH1009 voltage reference manufactured by Linear Technology. Two types of packages are included: cans and flatpacks. The can packaged devices from the same lot date and wafer have also been qualified at high dose rate previously. The 5 mrad(Si)/s data show enhanced degradation rates relative to the high dose rate data. Additionally the 5 mrad(Si)/s can packages showed decreasing (negative-going) V_{out} with total dose, which is in contrast to the increasing (positive-going) trend displayed in the flatpacks at 5 mrad(Si)/s and the high dose rate can packages. The different behaviors of the cans and flatpacks are possibly due to radiation drift and/or part-to-part variation. The pre-irradiation values for the reference voltage lie slightly above and below the target 2.5 V for the flatpack and can devices, and increase or decrease with total dose. The different device packaging may also have caused the different degradation behaviors. However additional data points from 1 and 0.5 mrad/s dose rates are needed for a more conclusive analysis.

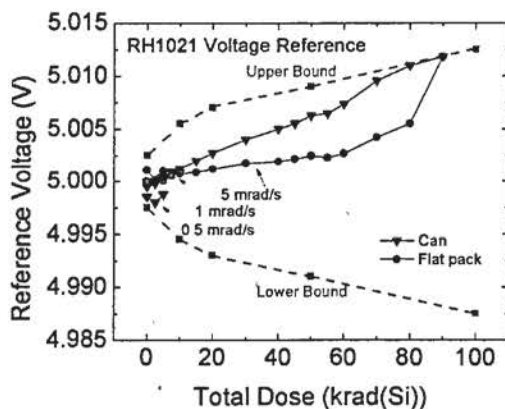


Figure 3. Average reference voltage (4 parts) vs. TID for the RH1021 voltage reference from Linear Technology, irradiated with all pins grounded.

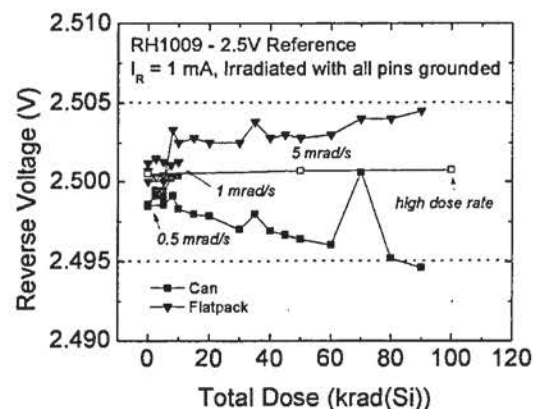


Figure 4. Average reference voltage (4 parts) vs. TID for the RH1009 voltage reference from Linear Technology, irradiated with all pins grounded.

Conclusion

We have provided an update on the current status of ultra-low dose rate irradiations. The results are varied depending on the device. Even parts of similar function and manufacturer exhibit different degradation behaviors. We found possible dose rate effects in the TL750L voltage regulator, which had device failures occurring earlier for lower dose rates. The enhanced degradations exhibited by the RH1009 indicate that high dose rate qualified devices are susceptible to ELDRS at very low dose rates. The ELDRS-free LM158 showed greater degradations for high dose rate relative to low dose rate irradiations.

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